The Influence of Muscular Exertion Upon Mental Performance

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TO
R. AND J. B.
GRATEFULLY

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CHAPTER I

THE PROBLEM AND THE LITERATURE

Three uses of the familiar term 'tension' may be distinguished in the current psychological literature. There is, to begin with, Jacobson's use, in his book *Progressive Relaxation*, where 'tension' seems to signify a somewhat vaguely defined condition of "nervous hypertension" (p. 6) or nervous hyperexcitability. A second, somewhat more common usage makes tension synonymous with 'tonus', a chronic state of contraction in the skeletal and smooth muscles. According to the latest fashion in considering the matter (Freeman (5)), tonus is largely self-maintained as a proprioceptive reflex, but is subject to cerebral influences. A third usage makes 'tension' equivalent to voluntarily and consciously induced contractions of the skeletal musculature (Bills (1), *et al.*). It seems clear from his writings that what Jacobson means by nervous hypertension is really an abnormally increased amount of tonus. The author therefore suggests that the term 'tension' be reserved exclusively for tonus of the skeletal and smooth musculature, and that some such phrase as 'muscular exertion' be substituted for 'tension' in the third sense.

The study of the rôle of muscular processes in mental tasks has, as Freeman points out (5), progressed along two lines. "In the first class of researches the problem has been to vary some phase of higher behavior to observe its effects upon the tonus accompaniments. Other researches have had as their problem to observe the effects of variations in muscular tension (exertion) upon behavior." The problem undertaken here is of the second variety and may be stated as follows:

(1) Do experimentally varied muscular exertions have any functional relationship to the efficiency of mental performance?

(2) Does this relationship, if it exists, vary with the kind of mental task?

(3) Is there an optimum degree of muscular exertion at which mental efficiency is highest?

Evidence that muscular tonus, or tension, at times accompanies various mental processes comes from the work of Tuttle (24), Jacobson (14), Golla and Antonovitch (10), Freeman (4, 7, 8), Stroud (23) and others. A recent summary of all this work may be found in Henley's monograph (12). The precise nature of the

relationship between tonus and mental processes is still, however, a matter of doubt. The crucial question, for example, whether peripheral activities are overflow phenomena (as Lashley (17) seems to imply) or whether they are an essential condition for the maintenance of cortical processes, has not been settled.

This second hypothesis has been proposed by Freeman (among others) who sets forth what he calls a 'central facilitation theory' in his *Introduction to Physiological Psychology* (5) and in an article in the *Psychological Review* (6, 1931). Briefly stated, Freeman's theory runs something like this: Proprioceptive impulses, travelling to the cortex (chiefly via the extrapyramidal system (5)) may be supposed there to raise the level of cortical vigilance (a concept borrowed from Head) and thus to facilitate cortical processes. Or, stated in a slightly different way, proprioceptive impulses combine and summate with other impulses present in the cortex at any given time, thereby lowering the response threshold of cortical centers. Two other hypotheses are included in the detailed statement of this theory: (1) That cortical thresholds "vary with the level of functional activity. Thus, while the same centers might be involved in both perception and memory,—the critical threshold might be lower for the perceptual than for the memorial processes." (2) That "above a certain maximum, muscular contraction may become an inhibitor of precise neural integration. The facilitative effect is only within limits, which vary presumptively from individual to individual." But these two hypotheses are accessory to the fundamental assumption that "cortical action is reinforced and sustained by a continuous stream of proprioceptive impulses."

Freeman cites, in support of this theory, some of the evidence listed above, as well as evidence from the second type of approach to the problem of motor activities and consciousness, of which Bills' study was the pioneer research.[1] Bills' work has been widely quoted as showing that voluntarily induced muscular exertion was accompanied by increased efficiency in several kinds of mental work, *viz.*, learning nonsense syllables, paired associates, adding columns of 20 digits and naming letters.

A close analysis of Bills' results reveals, to begin with, that the group-average differences are in the direction of exertion advantage in all four sections of the experiment, and are statistically reliable. Not all of Bills' subjects, however, show the facilitative effects of

[1] For a summary of earlier fragmentary work more or less relevant to this specific problem, see Bills (1).

exertion. As a matter of fact, the increases in mental efficiency are subject to wide individual differences, occur irregularly in the same and different subjects, vary with the criterion of efficiency used and, most important of all, are counterbalanced by a sometimes alarmingly large proportion of cases where no increase in efficiency is reported. Certainly it appears that Bills' conclusion—". . . muscular tension of the form and amount used by us does increase the efficiency of mental work of the kinds tried" (p. 249)—should have been qualified by some mention of these important irregularities:

Nine subjects were used for learning twenty lists of nonsense syllables, ten in each of two conditions (exertion and control). Where learning time was the criterion of efficiency (number of responses necessary for one perfect recital), 3 of the 9 subjects did not show the advantage in favor of the exertion series. Where the number of syllables recalled after a period of time was the criterion, 2 subjects did not show the advantage and 2 others showed very slight differences (of the order of 0.1 and 0.5 more syllables recalled). Where re-learning time was the criterion, 2 other subjects again showed no advantage and 3 others showed extremely slight differences (0.3, 0.8, 0.8 repetitions). Where per cent time saved in re-learning was the criterion, 2 subjects again showed no advantage (not the same two subjects) and 4 others showed negligible differences. Practice curves for the 9 subjects showed a greater decrease in learning time under exertion, but the *opposite effect* where the number of syllables recalled and per cent time saved were criteria.

Eleven different subjects were used in the addition test. Here 3 subjects showed differences in favor of the exertion series which fell below the requirements for statistical significance, and 2 cases were on the borderline of statistical significance.

In letter reading, ten new subjects were used. Two cases showed no advantage for exertion and two others showed unreliable differences.

Learning paired associates (ten additional subjects) showed all individuals recalling more of the material which had been presented under exertion conditions than of the material which had been presented in the 'normal' series. Here, however, exertion was not used in the actual recall situation. One might very reasonably point out, in this connection, that the additional exertion during learning could simply have made this series of paired associates more vivid, thus obviously facilitating subsequent recall. It might be argued, of course, (*cf.* Guthrie (11)) that the increased vividness in the exer-

tion series was a function of an increased number of proprioceptive impulses. The point is, however, that Bills did not here directly demonstrate the influence of proprioceptive impulses on ease of recall. Increased vividness might be a function of unfamiliar and artificial conditions of work created by muscular exertion, or of irritation caused by muscular exertion, or of annoyance, as well as of proprioceptive impulses.

Freeman himself attacked the problem from both angles, using as a measure of tonus, and of exertion, changes in quadriceps tonus, photographically recorded (1). The parts of his researches which directly concern us are those in which quadriceps tonus changes were experimentally induced (either directly, by instructions to the subjects, or indirectly, by varying the subjects' motivational set) and the concurrent changes in performance studied. Freeman's subjects did continuous addition under three motivational conditions—"super-maximal" ($5 reward), "maximal" (verbal incentives) and "sub-maximal" (no chance to win the reward). Table I shows the results for the 8 subjects in this experiment.

TABLE I
(After Freeman)
Showing effect on continuous addition of varying motivation
(N = 8)

	Max. Incentive	*Sub-Max. Incentive*	*Super-Max. Incentive*
Av. # Responses	20	17	22
Av. # Errors	4.4	4.5	7.9
Av. Tonus	19.3	24.9	54.6

It will be seen from this table that speed of continuous addition increases slightly (compared to "maximal incentive") in "super-maximal" motivational and tonus conditions, but that accuracy decreases. It should also be noted that the differences are quite small, and that Freeman presents no measures of variability.

When exertion was directly induced by instructions to subjects, reaction time to weak sounds was materially decreased, but much less strikingly decreased in the case of loud sounds. The number of subjects in this part of Freeman's study, however, was only 4.

In manual tasks, likewise, no consistent facilitation effects could be demonstrated, when exertion was induced directly. Having the subjects sustain different weights with the left arm, while reacting with the right finger, showed an accompanying increase in the work

output in finger oscillation. But, once again, manual pursuit, a more highly integrated act, was definitely hindered by the increased exertion. Freeman further found that the more remote the muscle group in which exertion was artificially induced, the less the facilitative effect in the finger oscillation task, oscillation of the right index finger being most rapid when flexors of the right middle finger were under spring tension (exertion) and least rapid with left quadriceps tension.

Stroud's experiment (23) has one section relevant to our problem. The effects of artificially induced tension, obtained by having each of 32 subjects sustain a 14 pound weight with the outstretched left arm, while the right hand traced a stylus maze, were studied. The effect on an easy, short maze was to increase speed and decrease errors (differences unreliable), although the number of trials to learn was unchanged. When a longer, more difficult maze was attacked, induced tension (exertion) decreased time, errors and number of trials to learn (differences conventionally reliable). Stroud suggests that the beneficial effects of exertion are greater in more difficult tasks since exertion has an influence equivalent to that of effort. These results seem to conflict with Freeman's, where the facilitative effects of exertion were confined to simple, rather than to complicated manual tasks. It is doubtful, however, whether the two studies can really be compared, since not only the method of inducing tension, but also the type of motor task was so different.

Lastly, Zartman and Cason (25) investigated the effects of muscular exertion on efficiency in solving arithmetical problems. Eighteen subjects were required to push with the right foot against a brake pedal, keeping the pressure exerted somewhere between 25 and 40 pounds. Kymographic records were kept of the amount of pressure exerted. Correlations between the amount of foot pressure and efficiency were low and negative; individual differences were, as in Bills' study, frequent. Zartman and Cason's conclusions are negative, *i.e.,* foot pressure has no effect on mental efficiency.

The trend of all this evidence concerning the relationship between muscular exertion and mental efficiency seems, then, somewhat confused, at least where non-manual, or so-called higher mental tasks are involved. A review of the literature reveals, further, many variables which ought to be controlled in future experimental work. (1) *The existence and degree of tension* (*exertion*). Bills took no record of the actual amount of exertion expended by his subjects in squeezing two dynamometers. A "comfortable" amount of pres-

sure was agreed upon for each subject in preliminary trials, to which the subject adhered in all subsequent work. Bills abandoned his original kymographic recording device because the subjects seemed to vary so little during the work from the pressure assigned to them. It is just possible that some of his negative results were instances in which the subject was actually not squeezing the dynamometers, or not exerting enough pressure, although our findings on this point (see below, p. 37) would seem to destroy the possibility. At any rate, a record, preferably continuous, of the exertion expended by the subjects (as measured in pounds of work) seems essential to any careful study. (2) *Tensions in control series.* Both Bills and Zartman and Cason failed to check on possible tonus changes occurring when the subjects were supposed to be at rest. It is, of course, impossible to obtain, by any known technique, tonus changes in all parts of the body at once (and even extremely difficult to obtain accurate records for small, isolated portions of the body). An elementary check, however, would be to arrange a fairly delicate recording system for 'control' tensions in those parts of the body where exertion is induced in the experimental series. (3) *The parts of the musculature involved.* It is conceivable that the difference between Zartman and Cason's and some of Bills' positive results may be ascribed to the difference in the parts of the musculature involved in both studies. Foot pressure may, for some reason (difficult to imagine)[2] be inherently less beneficial than hand pressure. Or it may be that, as Zartman and Cason suggest, foot pressure offers less of a distraction to the subject at work, as a consequence of which he is temporarily somewhat less efficient (*cf.* Morgan (18)). (4) *The kind of mental task.* Bills' mental tasks were somewhat less difficult than Zartman and Cason's. It is possible, and there is some slight evidence for such a belief (see above, Freeman's results and Bills' results), that proprioceptive impulses might act to increase the speed of rote manual and mental processes, while for more complicated manual and mental tasks, the increased number of proprioceptive impulses streaming to the cortex might definitely be a hindrance to efficiency. Speed and accuracy ought there-

[2] On the basis of what we know about the non-specificity of cortical localization in higher mental processes. Freeman's findings (see above) that pressure on the finger has more facilitative effect on a simple manual task than pressure on the knee cannot be cited here. Physiologically, it is understandable that proprioceptive impulses from near-by muscle groups should be more effective in aiding a particular manual task than proprioceptive impulses from remote muscle groups. But that impulses from the feet should be any less helpful for complicated mental tasks than impulses from the hands seems logically doubtful.

fore to be treated separately when efficiency of mental performance is considered. (5) *An optimal degree of exertion.* Freeman's theory suggests the possibility that the facilitative effect on manual or mental work of an increased number of proprioceptive impulses would increase only up to a certain point, beyond which blocking (occlusion) might occur. This seems to be a reasonable assumption. Zartman and Cason's negative results might possibly be explained by supposing that insufficient exertion was required of the right foot, or, on the other hand, that the pressure exerted was above the optimal point. (6) *The distraction effect.* Theoretically, the distracting effects of muscular exertion should be separated from the 'pure' effect of increasing proprioceptive impulses. Whether it is ever possible to do this in a set-up involving voluntary, conscious action on the part of the subject seems doubtful. At best, one could merely attempt to minimize distraction effects by making the exertion as unobtrusive as possible. Since, further, the effects of distraction have been shown to decrease with habituation (*cf.* Ford (3), *et al.*), results should be analyzed for the changes in 'exertion' effect when the work is continued over fairly long periods of time. Bills' finding (see above, p. 7) that with practice the curves for learning nonsense syllables (when amount recalled and per cent saving were criteria) tended to approximate each other, might be mentioned in this connection.

CHAPTER II

THE PROCEDURE

A. Apparatus

An apparatus was constructed which allowed the subject to exert a stated amount of hand and foot pressure, at the same time that he did mental work. Record in pounds was kept of the degree of pressure exerted. The apparatus was so constructed that it was impossible for the subject to do the mental work unless he was maintaining a steady degree of pressure.

(1) *The Chair*

A wooden chair, equipped with hand-grips (A) and foot pedals (B) was specially built for use in this experiment.[1] Two upright handle-bars were fastened on the arms of the chair; two wooden 'brake pedals' were placed at an appropriate angle for each subject. Each handle-bar and foot pedal was attached by a lever system (C) to a set of springs (D) of known resistance, which in turn moved a wooden disk (E) on which were 4 contacts to a Bristol polygraph (F).[2] A record of 4 degrees of pressure above the minimum created by a particular set of springs was thus available for each hand and foot. A wide range of variations in pressure was made possible by varying the springs.

(2) *Control Records*

Extremely light springs were inserted by the experimenter before each control series. The subjects 'rested' their hands and feet on the pedals and grips during the control records.

(3) *The Signal Box*

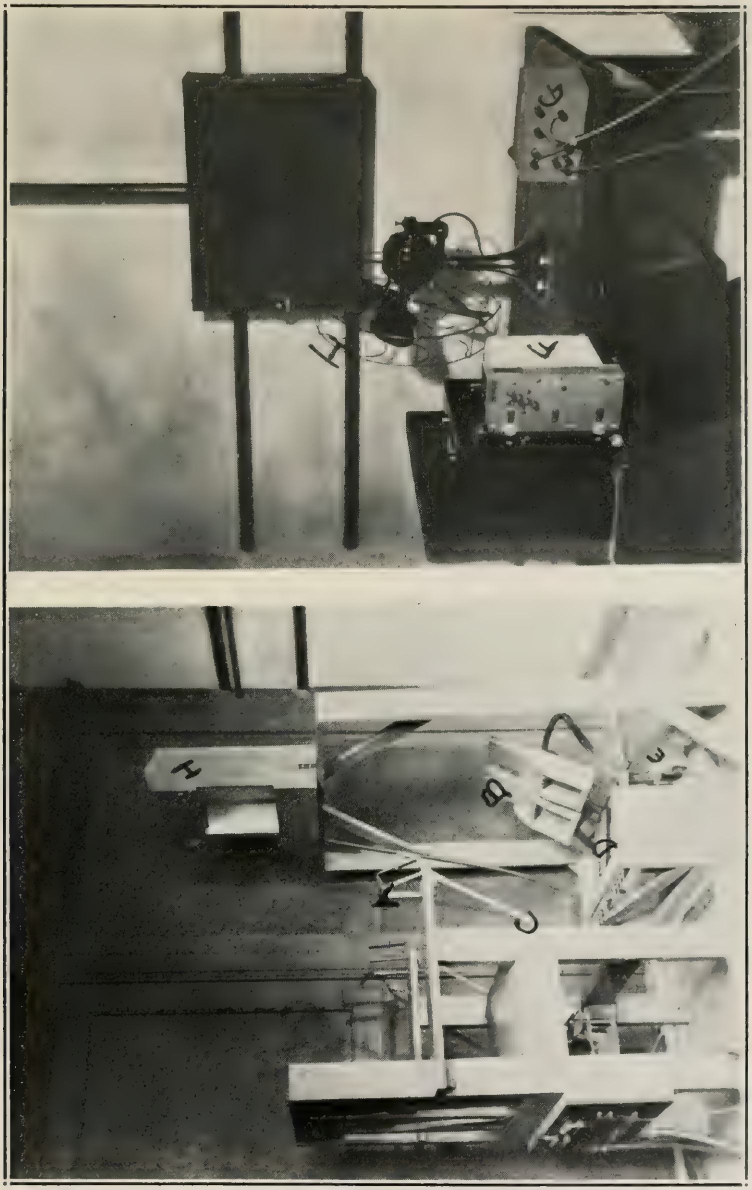
Four additional contacts on the wooden disk were connected to the experimenter's signal box (G) placed on the experimenter's work table, giving her an instantaneous record of the degree of pressure exerted.

(4) *The Exposure Box* (H)

A wooden box ($19'' \times 12''$) was placed in the subject's line of vision. A slit at the back of the box allowed insertion of the mate-

[1] The letters in parentheses refer to the photograph facing this page.

[2] Each spring was previously calibrated by means of a spring-balance, not only for minimum resistance, but for the four degrees of stretch corresponding to each contact.


H
A
D
H
B
C
D
E

rials to be used in the experiment. The box was illuminated from the experimenter's signal box by three sets of lights: ordinary white light signified to the subject that he was maintaining a steady degree of exertion; green light, that he was pressing too hard; red light, too little. It was thus impossible for S to do the mental task unless he held a steady degree of pressure. This set-up has the obvious advantage of maintaining a constant check on the amount of pressure exerted by the subject. It is also possible that a certain integration of the mental task with the physical task was obtained (after the subject became accustomed, as he quickly did, to the signal system), since the performance of the mental task was in a sense dependent on keeping a steady pressure. It was hoped, by this method, to render the exertion a somewhat less obstrusive part of the experimental set-up (see above, p. 11).

(5) *The Sound-Screen*

An electric fan (I) was started five minutes before the subject entered the chair and kept going throughout the duration of the day's work. The noise of the fan served the principal function of screening intermittent outside noises, and also of drying the ink on the Bristol recorder.

B. The Subjects

Fifteen Brooklyn College students ranging in age from 17 to 21 years served as subjects. All were males employed by the college as part of the National Youth Administration. The subjects are designated throughout the presentation of results by Roman numerals. Subjects I–XIV served in the continuous addition part of the experiment; subjects VI, XI, XII, XIII, XIV and XV were absent from the syllogisms tests; only subjects I–X did analogies; and subjects II, III, V, VIII, IX, X and XV took part in the determination of optima. None of the subjects was familiar with the purpose of the experiment.

C. The Materials

An attempt was made to include in the experiment mental work at three levels of difficulty (see above, p. 10). For simple, rote mental work continuous addition was chosen, presumably involving operations already familiar to the subjects. An analogies test was chosen to represent the next level of difficulty; here, functions of a somewhat 'higher' nature are involved in the seeing of relationships. A test of syllogistic reasoning was used, finally, as the third and

highest level of difficulty. Since the task here was quite unfamiliar to all the subjects, none of whom had ever received any training in formal logic, it may be supposed that the difficulties already inherent in drawing strictly logical inferences from a set of premises were even enhanced. A detailed description of the tests used follows:

(1) *Continuous Addition*

Each subject was given these instructions: "The task required of you now is continuous mental addition. Start with number 16 and to it add 17 and report to me the total. To this total add 18, and to the next total, 19, then 18, then 17, then 16, then 17, then 18 and so on, until I tell you to stop. Report aloud to me each subtotal as you get it. Begin when I say 'ready' and add until I tell you to stop." Each trial consisted either of a 3 minute period followed by a 2 minute rest (or, in the latter part of the experiment, where the problem of optima was attacked (see below, p. 17), of a 30 second period followed by a 15 second rest). The subject was started with a different number each trial; this number was taken at random from some point in the series. Each response was recorded by the experimenter, and the results scored for speed, *i.e.,* number of responses in the stated period, and accuracy, *i.e.,* number of errors made. Four control and four exertion trials, arranged in 'chance' order (for example, C C E C E E C E) constituted a day's work.

(2) *Analogies*

These were derived from a graded series published by Pintner and Renshaw (19). The test is of the multiple-choice type and the subject was required to respond by saying the correct word aloud. Time in seconds was recorded for each answer and the results also scored for accuracy. Four series of analogies were constructed, each containing 48 analogies of approximately equal difficulty, as determined by Pintner and Renshaw's Point Scale. Eight analogies were typed in large letters on white paper, which was then mounted on cardboards of appropriate size for insertion in the exposure-box. Six cards (3 control and 3 exertion) thus comprised a series, presented likewise in 'chance' order.

(3) *Syllogisms*

Two hundred twenty syllogisms were used, mostly derived from a test constructed by Sells (20).[3] The syllogisms were all of the

[3] The author is indebted to Dr. S. B. Sells for making his test available to her.

abstract type since Sells had found these to give more reliable results[4] than syllogisms in concrete form. The syllogisms were equated on the basis of Mr. Sells' results, which were, incidentally, also obtained on Brooklyn College students. Syllogisms of the same formal structure but differing in figure were found by Sells to be of equal difficulty, provided both of the syllogisms equated were either valid or invalid. The list of 220 syllogisms not identical but equivalent in difficulty was thus constructed without much trouble. Four syllogisms were typed on white paper which was then mounted on cards as before. Six cards constituted a series which thus contained 24 syllogisms equally divided between control and exertion, except for one section of the experiment where 100 syllogisms were presented in one sitting (50 control, 50 exertion). Each syllogism consisted (with one or two exceptions) of two premises followed by a conclusion. The subject was required to respond by saying 'True' if he thought the conclusion followed logically from the premises, or 'False' if he thought the conclusion was unjustified. Time for each response was recorded in seconds and the responses were also scored for accuracy.

D. The Conduct of the Experiment

(1) *Preliminary Experimentation*

It seemed reasonable to suppose that the amount of exertion required of each subject in the major part of the experiment ought somehow to be a function of that particular individual's muscular strength. The correlations occasionally reported in the literature between divers indices of muscular strength and height and weight were found to average around +.50 (Somerville (22)), so that neither the subject's height nor his weight could safely be used for predictive purposes. A more direct measure of each subject's strength was therefore indicated.

Six readings of the subject's maximum pull of a hand dynamometer were taken, three with the right hand alone and three with the left hand. The average for each of these two sets of readings was recorded for each subject. All 15 subjects made average scores ranging between 48 and 52 kilos for the right hand, and between 45 and 50 kilos for the left hand. (All subjects were right-handed.) Since the variations among the subjects in maximum pull were relatively small, it seemed fairly safe to set the amount of exertion

[4] Dr. Sells reports a corrected reliability coefficient of .9307 for a series of 180 abstract syllogisms.

required of each subject at the same point—34 lb. for each hand, or approximately 27% of maximum hand strength. The foot pedals were originally set for 48 lb. per foot. Too much discomfort was experienced by the subjects in pushing down both foot pedals at once; the left foot was therefore allowed to remain at rest during the main body of the experiment.

A preliminary habituation series extending over a period of a week and a half permitted each subject to 'get acquainted' with the chair. Each subject came three times for the habituation series and served for approximately one-half hour. No mental work was done during this period; the subjects simply practiced pulling the hand grips or pushing the foot pedals to the required amount, at E.'s command, and keeping a constant pressure. The light-signal system was introduced to the subjects at this time.

(2) *The Experiment*

The main body of experimental work lasted over a period of five months, beginning October, 1935, and ending in March, 1936.

(a) *Continuous Addition*

Five preliminary practice trials were given before the main series began. Data under conditions of hand pressure were collected first; then foot pressure was introduced. Each subject was tested for a minimum of 10 trials, depending on the subject's availability. Introspective reports were taken at the end of each trial. The subject was instructed to report "how the pressure felt" and was allowed to make any other general comment he wished.

(b) *Syllogisms Test*

The syllogisms test followed the continuous addition series. Hand pressure, foot pressure, and hands and foot combined were introduced in that order. Each subject, finally, solved 100 syllogisms at one sitting (50 control and 50 exertion), using hand pressure only. Introspective reports were now taken after each session. The subject was simply asked the routine question: "Anything to report?"

(c) *Analogies Test*

Solving analogies followed syllogistic reasoning. Hand pressure, foot pressure, and hands and foot combined were introduced in that

order. Introspective reports were taken, as in the syllogisms test, after each session.

(d) *Optima*

Seventy-five trials at continuous addition (see above, p. 14) were run for each subject, on three separate days. Five degrees of hand pressure were introduced: El—8lb. each hand; E2—15 lb. each hand; E3—22 lb. each hand; E4—48 lb. each hand; E5—56 lb. each hand. The order of exertion trials was varied each day, in order to eliminate the possible constant error attached to a given degree of exertion because of its position in the series. Thus,

Session I ...	C1	C2	E1	E1	C3	E2	E2	C4	E3	E4	C5
	E4	E5	C6	E5	E5	C7	E4	C8	E3	E3	C9
	E2	E1	C10.								
Session II ...	C1	C2	E5	E4	C3	E4	E3	C4	E2	E2	C5
	E1	E1	C6	E1	E2	C7	E3	E3	C8	E4	C9
	E5	E5	C10.								
Session III ...	C1	C2	E1	E2	C3	E2	E3	C4	E4	E4	C5
	E5	E5	C6	E5	E4	C7	E3	C3	E8	E2	E1
	C9	E1	C10.								

As in the syllogisms and analogies tests, introspective reports were taken after each session.

CHAPTER III

RESULTS

Part I. The Bristol Polygraph Record

(A) *The Exertion Record*

It was apparent early in the main experiment that the subjects readily maintained the constant degree of pressure assigned to them. This confirmed Bills' findings that his subjects varied little from the pressure required in his experiment. Indeed, the most striking fact revealed by an examination of the Bristol Polygraph record is an absence of deviations during the exertion series, especially in the last three tests. A few sporadic deviations were noted in the first continuous addition test, but these occurred principally in the early parts of this series. Thus, Subjects V, VI, IX, and X, who were the least steady of all the subjects, showed an average of 2 deviations each in the first 4 exertion trials, and thereafter maintained a constant degree of pressure. It is perhaps significant that these four subjects showed an advantage for exertion in speed of continuous addition (see below, p. 19), but not in accuracy.

(B) *The Control Record*

Light springs (3 lbs. for hand; 18 lbs. for foot) were inserted into the chair before each control reading. The subjects' hands and feet rested on the handle-bars and pedals during these sessions. At no time during the experiment did any subject exert enough pressure on the pedals or bars for a record to be made. One cannot, of course, infer from this fact that muscle tensions were not present during the control series. Only this may be stated—that insufficient contractions were present in those muscles of the subjects' bodies, which, if sufficiently contracted, would have moved the bars and pedals. Our recording device, in other words, was not sufficiently delicate for us to obtain adequate records of slight contractions in the arms and legs. Likewise, it may safely be said that those particular muscles of the body were considerably more 'tensed' in the exertion series than in the control.

Part II. Test Results

(A) *Continuous Addition*

Table I shows the differences in speed of continuous addition for 14 subjects under two conditions, exertion and control. Data taken

under hand exertion and foot exertion have been thrown together, since the scores of the subjects under these two conditions were not significantly different. The difference between the exertion and control averages for the group of 14 subjects is – 0.93; *i.e.*, 0.93 more responses were made in the control series. The reliability of this difference is 0.16, indicating that there are but 56 chances in 100 of its being significant. Subjects V, VI, IX, X, and XII showed some increase in speed of response during the exertion series. In 4 cases out of the 5, however, this increase in speed is accompanied by an increase in the number of incorrect responses given (see Table II). The 4 subjects who showed a compensatory increase in errors with increased speed are indicated by asterisks. Two subjects (I and VII) made exactly the same number of responses under both conditions and the other seven were quicker in the control series.

TABLE I

CONTINUOUS ADDITION

SHOWING AVERAGE NUMBER OF RESPONSES PER 3 MINUTE TRIAL

Subject	*Control*		*Exertion*
I	39.54		39.54
II	80.60		73.00
III	42.35		40.00
IV	57.50		51.50
V	43.50		46.10*
VI	52.10		52.40*
VII	64.87		64.12
VIII	51.70		49.00
IX	38.28		40.80*
X	51.65		55.25*
XI	23.50		22.75
XII	41.20		43.20
XIII	58.60		56.60
XIV	40.66		38.33
Mean	49.00		48.04
Diff.		–0.96	
D/σD		0.16	

* Indicates increase in speed accompanied by increased number of errors.

Table II presents the average number of errors made by the 14 subjects under control and exertion conditions. The difference between the two averages for all subjects is – 0.36; *i.e.*, 0.36 more errors were made in the exertion series than in the control series. The reliability of this difference is 0.31 which indicates that there are 62 chances in 100 that the difference is significant. Only three subjects (I, III, and XII) were more accurate in the exertion series; of these, only subject XII was also faster (see Table I). The other

11 subjects were consistently less accurate under exertion, although only four of them at the same time showed increases in speed of reaction.

TABLE II
CONTINUOUS ADDITION
SHOWING AVERAGE NUMBER OF ERRORS PER 3 MINUTE TRIAL

Subject	*Control*		*Exertion*
I	1.87		0.54
II	6.00		6.77
III	2.80		2.14
IV	7.50		9.50
V	3.22		4.44*
VI	3.46		4.00*
VII	4.00		4.50
VIII	3.75		4.50
IX	10.50		13.00*
X	3.58		4.50*
XI	3.25		3.50
XII	13.00		7.50
XIII	3.75		4.50
XIV	3.33		5.66
Mean	5.00		5.36
Diff.		−0.36	
$D/\sigma D$		0.31	

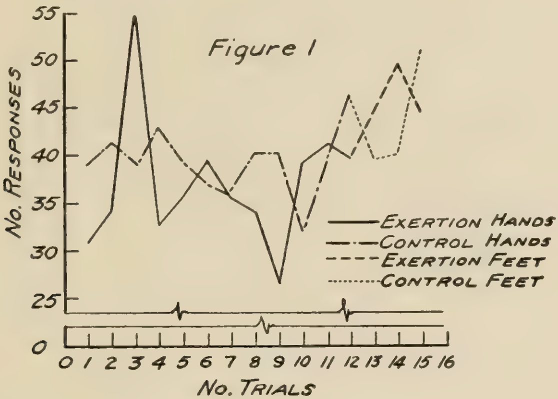
* Indicates increased number of errors accompanied by increased speed.

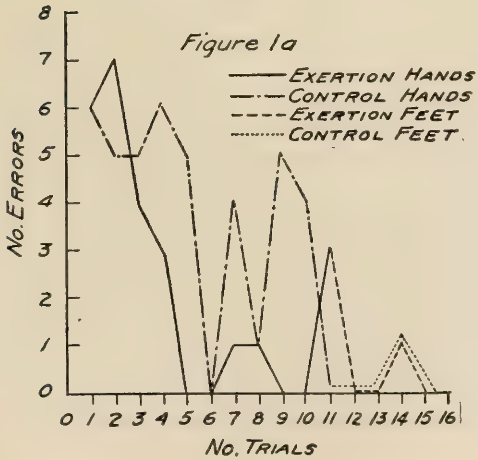
Figures 1, 2, 3 and 4 are representative of typical practice curves for individual subjects.[1] We shall consider first the practice curves where speed is the criterion. Perhaps the most striking tendency revealed by inspection of these curves is the close parallelism between the progress of efficiency in control and exertion series. The curves for control and exertion cross each other frequently and are unmistakably similar in trend. Figures 1 and 2 show some slight indication that the convergence between control and exertion performance may increase as practice continues. Figures 1, 3 and 4 show that speed of addition tends to be greater in early exertion trials than in early control trials, but that this difference diminishes or is even reversed with practice. This trend recalls Freeman's, Golla and Antonovitch's, Henley's and Ghiselli's (9) recent findings that the tonus accompaniments of mental performance are greatest at the beginning of work and subside as familiarity with the task improves.

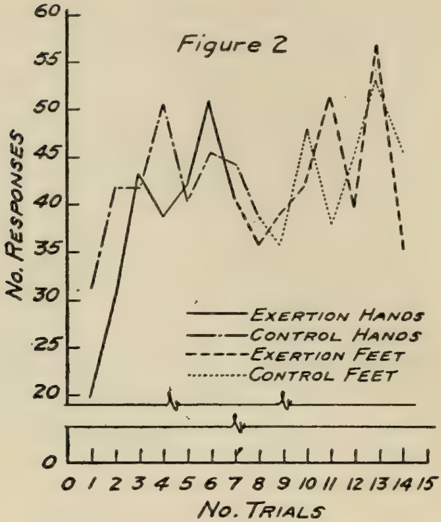
The practice curves for accuracy (Figs. 1a, 2a, 3a, and 4a) show the same tendency for convergence with practice, with the possible

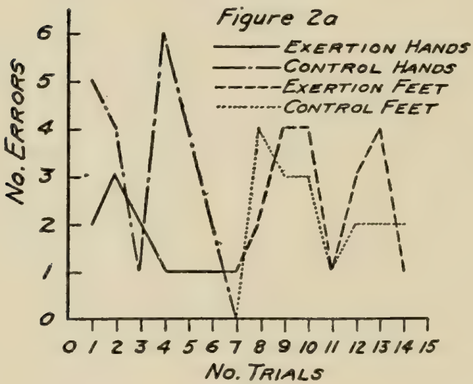
[1] The raw data for all 14 subjects may be found in the Appendix.

exception of Fig. 3a, where the curves show marked divergence at the last trial. It is interesting to note that, for the most part, the number of errors is greater in the early exertion trials than in the early control trials (Figs. 1a, 3a and 4a). This is possibly an indication that physical exertion was highly distracting at the beginning of work and less of an annoyance as work progressed. Considered together with the increased speed of addition in early exertion trials, this decrease in accuracy seems to indicate the complexity of the situation in which the subject finds himself. The distracting effects of voluntary physical exertion may possibly induce the subject to speed up his responses, at the cost of accuracy. Of it may be that exertion has, initially, a slightly facilitating effect on speed, while its effect on accuracy is initially inhibitory. At any rate, the joint action of facilitative and distracting effects is difficult to disentangle in the present experiment.



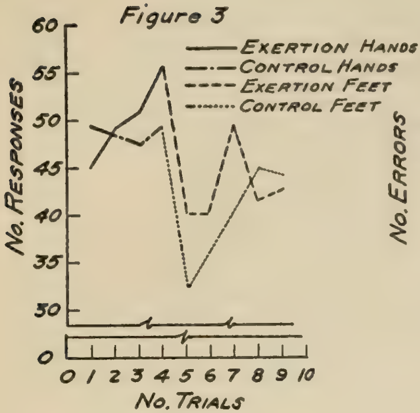


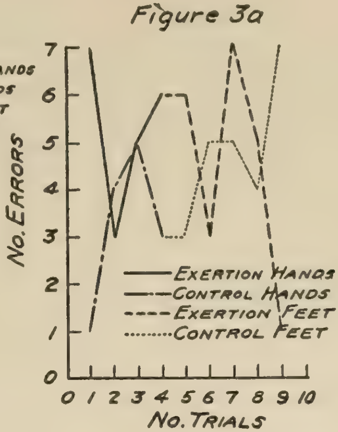


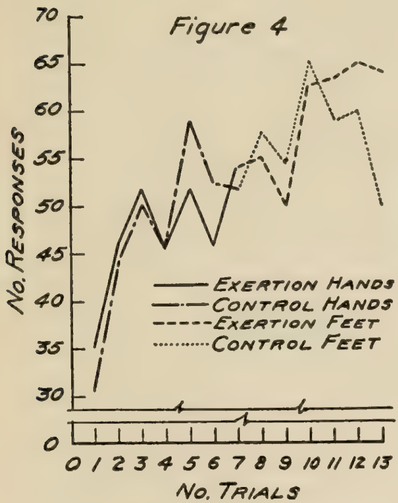


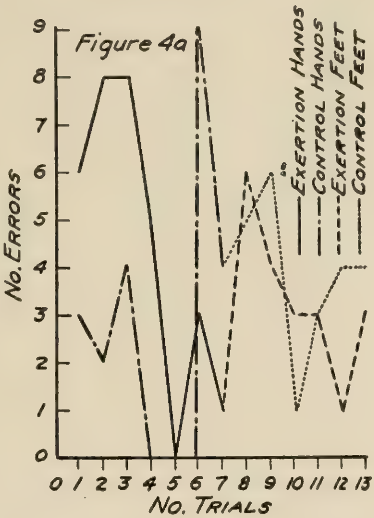
Introspective Reports

The subjects' introspections, taken at the end of each trial in this first experiment, reveal little of value to us in interpreting our results. The introspections from the early parts of the continuous addition series may be classified into two groups—(A) 8 subjects (I, II, III, V, IX, X, XIII and XIV) who found exertion annoying; and (B) 6 subjects (IV, VI, VII, VIII, XI and XII) who reported being able to forget completely about the pressure required, or who had "no report." None of our subjects was trained in introspective method, which, of course, somewhat reduces the value of their verbal reports. It was thought inadvisable to press the second group of subjects for further introspective comments, for fear of









suggesting to them that exertion should be more distracting than it was.

Of the eight subjects who found exertion an annoyance, three showed differences in favor of the exertion series in speed, but not in accuracy (subjects V, IX, and X). Of the six subjects who either gave no report or who "forgot about the pressure," two showed positive differences in speed (VI and XII); subject XII showed advantage in accuracy also. No generalization seems possible, therefore, regarding the relationship of the introspective reports to the behavior of the subjects.

TABLE III

SYLLOGISMS

Showing average number of seconds per response

	Hands				Foot				Hands-Foot				All conditions			
Subject	*C*	*E*	*D*	$D/\sigma D$	*C*	*E*	*D*	$D/\sigma D$	*C*	*E*	*D*	$D/\sigma D$	*C*	*E*	*D*	$D/\sigma D$
I ...	17.30	16.55	0.75	0.72	22.25	24.33	–2.08	0.16	12.33	13.00	–0.67	0.10	16.76	16.62	0.06	0.07
II ...	8.20	6.15	2.05	4.55	6.85	6.41	0.17	0.63	6.56	6.54	0.02	0.007	7.67	6.26	1.41	6.13
III ...	18.11	16.41	1.70	0.72	35.25	24.08	1.17	0.09	26.16	22.87	3.29	0.12	21.74	18.66	3.08	1.62
IV ...	10.07	9.73	0.34	0.46	8.50	8.91	–0.41	0.18	9.62	11.33	–1.71	0.22	9.80	9.99	–0.19	0.38
V ...	11.15	11.55	–0.40	0.43	11.66	12.50	–0.84	0.11	8.69	9.62	–0.93	0.11	10.68	11.23	–0.55	0.94
VII ...	16.76	13.85	2.91	2.84	13.83	19.88	–6.05	0.60	12.66	13.94	–1.28	0.16	15.53	14.53	1.00	1.53
VIII ...	9.87	9.87	0	0	14.00	12.41	1.59	0.23	9.29	9.75	–0.46	0.09	10.19	10.12	0.07	0.13
IX ...	6.15	7.50	–1.35	4.21	6.38	6.25	0.13	0.05	7.95	9.28	–1.33	0.50	6.57	7.33	–0.96	3.55
X ...	14.19	13.45	0.74	0.60	18.58	16.66	1.92	0.19	12.11	14.99	–2.88	0.22	14.21	14.14	0.07	0.07
Mean ...	12.42	11.75	0.67	0.33	15.23	14.60	0.63	0.21	11.64	12.22	–0.58	0.23	12.57	12.12	0.45	0.27

Summary

(1) Group-average differences for 14 subjects in speed and accuracy of continuous addition were small and unreliable.

(2) Practice curves for speed and accuracy show a remarkable similarity between the exertion and control series. There is also some tendency for the two curves to converge with practice.

(B) *Syllogisms Test*

Table III presents differences in speed of syllogistic reasoning under control and exertion conditions for 9 subjects. The differences between the averages under hand exertion, foot exertion, hands and foot and all conditions together are respectively, +0.67, +0.63, −0.58 and +0.45. There is, therefore, a very slight difference in favor of the exertion series, except where pressure is required from both hands and foot, when the direction of the difference is reversed. None of these differences, however, is at all reliable.

Considering, first, individual results under hand pressure, we find six subjects showing a difference in favor of exertion. Only one of these differences (subject II) is reliable. Two subjects show slight, unreliable differences in the reverse direction and one subject shows no difference. Foot pressure results show five advantages in favor of exertion and three in the opposite direction. None of these differences is reliable. Where hand and foot pressure are required, only two subjects (II and III) show increased speed of response (differences unreliable) while seven others show differences in the opposite direction. Subjects II and III consistently show an exertion advantage in the hand, foot, and hand-foot series, while subject V consistently shows advantage in the control series. When all exertion conditions are thrown together, six subjects show differences in favor of exertion (subject II again showing the only reliable difference) while three subjects show differences in the reverse direction.

Table IV shows the results for accuracy under hand exertion and with all exertion conditions combined. The differences between the averages in both cases are, respectively, −0.002 and −.02.[2] Five subjects show advantage in favor of hand exertion, 3 subjects show the opposite result and one subject (II) shows no difference. When all exertion conditions are combined, only 2 subjects show exertion

[2] Reliabilities of accuracy differences were not calculated. $\sigma_{Diff.} = \sigma_{Dis.} \sqrt{2-2r_{11}}$, when r_{11} is the reliability coefficient (Kelley (16)). $\sigma_{Diff.} = 20.50$; $r_{11} = 0.93$. $\sigma_{Diff.}$, therefore, $= 7.48$. The largest of our obtained differences, consequently, could not be reliable.

TABLE IV
SYLLOGISMS
Showing percentages of error

Subject	*Hands* Control	*Hands* Exertion	*All Conditions* Control	*All Conditions* Exertion
I	30	23	23	23
II	55	55	40	42
III	32	42	25	30
IV	47	44	42	42
V	32	42	28	38
VII	39	45	34	35
VIII	37	36	25	23
IX	37	32	34	33
X	51	42	39	43
Mean Diff.	–0.002		–0.021	

advantage, 6 show the opposite effect and 1 subject (I) shows no difference.

Additional effort was made to isolate the factor of distraction in this part of the experiment. Reference to the subjects' introspective reports (see below, p. 29) proved of little value, since the subjects uniformly reported that they "forgot about the pressure," during the solution of the syllogisms. It seemed possible that, if exertion were really an annoyance, the subject might, almost reflexly, hasten his answers, not dwelling long enough on a response to be sure of it. It might also be supposed that such a hastening of judgments would lead to an increased number of errors in the exertion series. This second assumption was not borne out by the data (Table IV), but the first possibility seemed worth checking anyhow. If annoyance were effective as a factor in reducing the time consumed in response, a distribution of speed in control and exertion series ought to show a reduced range in the exertion series. In other words, the distribution of responses in the control series ought to be more skewed at the shorter end. If no such factor entered, we should expect two overlapping curves, with similar constants. If the scores were distributed from lowest to highest, deciles calculated for both distributions and then ratios between corresponding deciles calculated, these C/E ratios should rise as we progress, if our hypothesis is correct.[3] Data obtained on 100 syllogisms solved by each subject at one sitting were used for this decile analysis.

Table V shows the actual ranges of time of response for each subject. 7 of the 9 subjects show varying reductions in range in

[3] We are deeply grateful to Dr. Max Hertzman for this suggestion concerning the statistical treatment of results.

TABLE V
SYLLOGISMS
Range of speeds

	Control	*D*	*Exertion*	*D*
I	6–41	35	6– 40	34
II	3–11	8	3– 14	11
III	4–52	48	4–100	96
IV	3–17	14	3– 16	13
V	5–29	24	5– 35	30
VII	5–41	36	6– 26	16
VIII	3–25	22	3– 20	17
IX	4–15	11	4– 14	10
X	5–43	38	5– 27	22
Mean		26.22		27.66

the exertion series. The average range for control responses is 26.22, while that for exertion responses is 27.66, however, unduly increased by the range for one subject (III) who took 100 seconds to make one response in the exertion series. If this response is disregarded, subject III's range in the exertion series becomes 39, in which case the average range for the exertion series becomes 21.33, or nearly 5 seconds less than that for control.

Figure 5 shows the distribution of C/E ratios between corresponding deciles for the nine subjects. We shall examine each graph separately. Subject I lends no support to our hypothesis that annoyance acted to reduce the time for slower responses; the ratios decline as we progress from the third to the tenth decile. Subject II shows markedly irregular fluctuations which likewise lend no support to our hypothesis. If the 'abnormal' response referred to above is disregarded, subject III seems to show an increase in C/E ratio as we progress from the first to the ninth decile. Subject IV shows the same irregular fluctuations which characterized subject II. Subject V shows considerably slower responses in the exertion series. Subject VII shows a U-shaped curve with a slight tendency for the ratios to increase as we go from the sixth to the tenth decile. Somewhat the same trend is shown by subject VIII. Subject IX shows a rather striking similarity of control and exertion responses in all parts of the curve. Subject X shows the same U-shaped tendency which characterized subjects VII and VIII, but the C/E ratio in the tenth decile is nearly equal to that in the first. Summarizing, then, only three subjects (III, VII and VIII) bear out our hypothesis, while the other six subjects show either opposite or irregular trends. Perhaps the only generalization which can be drawn from this statistical treatment of the data is that wide

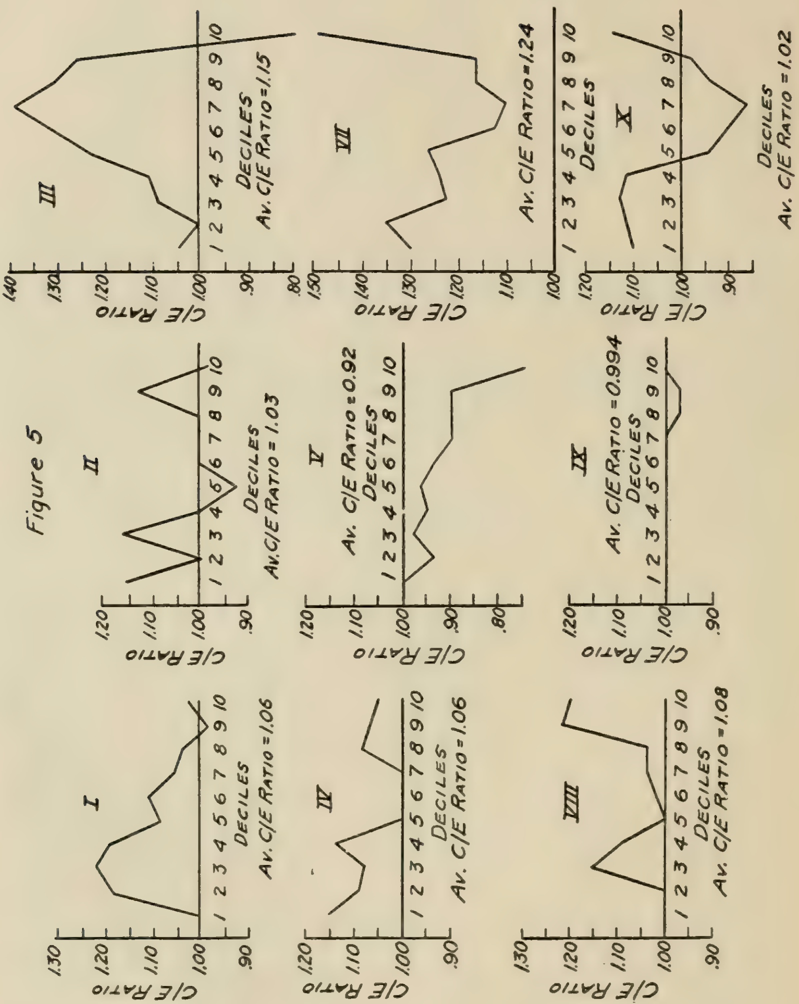


Figure 5
I
DECILES
Av. C/E RATIO = 1.06
II
DECILES
Av. C/E RATIO = 1.03
III
DECILES
Av. C/E RATIO = 1.15
IV
DECILES
Av. C/E RATIO = 1.06
V
Av. C/E RATIO = 0.92
DECILES
VII
Av. C/E RATIO = 1.24
DECILES
VIII
DECILES
Av. C/E RATIO = 1.08
IX
Av. C/E RATIO = 0.994
DECILES
X
DECILES
Av. C/E RATIO = 1.02
C/E RATIO

individual differences in speed of response were exhibited under both conditions.

Introspective Reports

The subjects' introspections were taken after each sitting. By now, all nine subjects had "no report" to offer. Additional questioning aimed at isolating the effects of exertion revealed that all the subjects were able to "forget about it." Again, it is impossible to relate the subjects' introspections to their behavior in the syllogisms test.

Summary

(1) Differences between group averages for speed and accuracy of solving syllogisms were insignificant and unreliable under all exertion conditions.

(2) Individual differences are so marked that no unequivocal generalizations may be made.

(3) An effort to isolate the distraction factor by statistical analysis of the distributions of speed proved fruitless.

(C) *Analogies Test*

Table VI shows average differences for the three exertion conditions and for all exertion conditions combined. We shall consider the results for each exertion series separately. Under hand pressure, the differences between the averages for all 10 subjects is + 0.03, with a D/σ_D equalling 0.03, indicating no reliability. Five subjects show differences in favor of exertion; only one of these differences (subject II again) is reliable. Five other subjects show advantage for the control series.

The difference between the averages under foot pressure is − 0.04 ($D/\sigma_D = 0.08$). Five subjects (not the same individuals as above) show exertion advantage; four, control advantage and one, no difference. The difference between the means for the hand-foot exertion is + 0.88 ($D/\sigma_D = 0.50$). Six subjects show advantage for exertion, four, advantages for control. When all exertion conditions are combined, the difference between the means for all subjects is + 0.29 with a reliability of 0.36. Seven subjects show exertion advantage, three, control advantage. It should be noted that subject II, who has been showing reliable differences in favor of exertion thus far, now shows insignificant, unreliable differences in favor of control sessions.

The results on accuracy in selecting analogies are presented in

TABLE VI

ANALOGIES

Speed—showing average time response (sec.)

	Hands				Foot				Hands and Feet				All Conditions			
	C	*E*	*D*	D/σ_D	*C*	*E*	*D*	D/σ_D	*C*	*E*	*D*	D/σ_D	*C*	*E*	*D*	D/σ_D
I	7.17	6.44	0.73	1.44	4.91	5.21	–0.30	0.84	10.55	8.79	1.76	0.81	7.54	6.81	0.73	1.83
II	3.56	3.38	0.18	10.58†	3.21	3.00	–0.21	0.64	4.50	5.28	–0.78	1.81	3.76	3.89	–0.13	0.69
III	5.00	4.29	0.71	2.37	4.83	4.04	0.79	1.83	11.75	11.92	–0.17	0.09	7.19	6.75	0.44	1.25
IV	10.98	10.52	0.46	0.39	7.88	9.16	–1.28	1.29	13.00	11.25	1.75	0.95	10.62	10.31	0.31	0.39
V	5.58	6.10	–0.52	1.15	4.98	5.34	–0.36	0.76	10.96	7.75	3.21	2.91	7.17	6.39	0.78	2.35
VI	8.76	9.09	–0.33	1.13	5.54	5.66	–0.12	0.25	10.21	10.83	–0.62	0.50	8.17	8.53	–0.36	0.58
VII	4.54	4.69	–0.15	0.41	4.13	4.00	0.13	0.39	7.88	6.58	1.30	1.55	5.51	5.09	0.42	1.55
VIII	4.72	5.46	–0.74	2.49	4.67	4.25	0.42	0.13	11.29	8.80	2.49	2.98	6.89	6.17	0.72	2.07
IX	4.38	4.34	0.04	0.17	4.50	4.50	0.00	0.00	5.92	6.13	–0.21	0.28	4.93	4.99	–0.06	0.35
X	6.61	6.63	–0.02	0.06	6.00	5.96	0.04	0.09	13.42	13.34	0.08	0.06	8.68	8.64	0.04	0.09
Mean	6.13	6.10	0.03	0.03	5.07	5.11	–0.04	0.08	9.95	9.07	0.88	0.50	7.05	6.76	0.29	0.36

† While the probability that the difference in this particular instance is greater than zero is very high, the difference is not a very significant one. The ratio of the difference to the control is 5.1 in percent (.051). The high critical ratio is a function of the unusually low variability of the subject in question in this particular situation.

TABLE VII
ANALOGIES
Average number errors

	Hands			*Feet*			*Hands & Feet*			*All conditions*		
	C	*E*	*D*	*C*	*E*	*D*	*C*	*E*	*D*	*C*	*E*	*D*
I	1.00	1.17	–0.17	0.00	0.33	–0.33	1.33	3.33	–2.00	0.78	1.61	–0.83
II	1.17	1.17	0.00	0.33	0.66	–0.33	3.00	3.66	–0.66	1.50	1.83	–0.33
III	0.83	0.33	0.50	0.66	0.66	0.00	2.66	2.00	0.66	1.38	.996	0.38
IV	2.17	2.33	–0.16	0.33	0.66	–0.33	3.33	1.66	1.67	1.94	1.55	0.39
V	0.17	0.33	–0.16	1.00	1.33	–0.33	1.66	1.33	0.33	0.94	1.11	–0.17
VI	0.33	0.66	–0.33	1.00	0.66	0.34	3.00	2.33	0.67	1.44	1.22	0.22
VII	0.50	0.33	0.17	0.66	0.33	0.33	2.66	2.00	0.66	1.27	0.89	0.38
VIII	0.33	0.33	0.00	0.00	0.66	–0.66	4.00	1.33	2.67	1.44	0.77	0.67
IX	0.16	0.50	–0.34	0.33	0.33	0.00	2.66	0.66	2.00	1.05	1.22	–0.17
X	0.16	1.00	–0.84	0.66	0.66	0.00	1.33	3.00	–1.67	0.72	1.55	–0.83
Mean	0.68	0.82	–0.14	0.50	0.63	–0.13	2.56	2.13	0.43	1.15	1.17	–0.02

Table VII. Reliabilities of differences were not calculated.[4] The differences between the means for 10 subjects were, respectively, – 0.14, hand pressure; – 0.13, foot pressure; + 0.43, hand-foot pressure; and – 0.02, all conditions. Under hand pressure, two subjects are more accurate (III and VII), six less accurate and two show no difference. Under foot pressure, two subjects are more accurate (VI and VII), five less accurate and three show no differences. When hand and foot pressure are required, seven of the subjects show increased accuracy, while three show decreases. This trend, incidentally, is exactly contrary to the results for syllogisms, where hand-foot pressure made the poorest showing. When all exertion conditions are combined, five subjects show exertion advantage; five, control advantage. All differences are slight.

Introspective Reports

Introspections were again taken after each sitting. The subjects uniformly had "no report" to make.

[4] Pintner and Renshaw do not report the $S.D._{Dis.}$ or the reliability coefficient of their test. Smith (21), however, presents data on a series of 50 verbal analogies given to 186 City College students. Since the length of Smith's test is approximately the same as that used in each part of our series, and since, further, the type of population used is the same in both studies, it seems reasonable that we may use the constants presented by Smith for evaluating the accuracy scores of our subjects. The maximum difference in accuracy between a control and exertion situation is only four items (for any one subject). Using Smith's data, we find that the $\sigma_{est.}$ between two forms of such a test will be 3.6 items. Using 3 times this value (as is usually done) in determining whether our difference may have arisen by chance, we find that the value of 10.8 thus obtained is considerably larger than our largest difference of 4. We may consequently conclude that the difference in the control and exertion conditions could not have caused the obtained differences in accuracy.

SUMMARY

(1) Differences between means for a group of 10 subjects in speed and accuracy of selecting analogies are small and unreliable.

(2) Examination of individual differences shows no consistent trends. All differences are small and unreliable.

(D) *Optima*

It will be remembered that the last of our problems was a check on the possibility that the facilitative effects of exertion exist within limits, or, in other words, that an optimal degree of exertion exists, above and below which no facilitation, but, on the contrary, inhibition might be demonstrated. This possibility was an accessory hypothesis to Freeman's theory and seemed reasonable, at least by analogy with what is known about the effects of increased sensory stimulation upon the responses of single nerve fibers. In the intact organism, it might perhaps be supposed that abnormally increasing the number of proprioceptive impulses streaming to the cortex would disorganize or destroy the complex pattern of neural impulses underlying a required response, while too little proprioceptive stimulation would fail to supply the "supporting" neural background for the response. Our negative results in the first three sections of this experiment could then be explained by supposing that too much or too little exertion had been required of our subjects.

The continuous addition test, considerably shortened, principally in order to avoid the possible strain of holding a high degree of

TABLE VIII

OPTIMA

Average number responses per 30 sec. trial in continuous addition

	C	*8 lb.* E_1	*15 lb.* E_2	*22 lb.* E_3	*48 lb.* E_4	*56 lb.* E_5	E_{all}	D	D/σ_D	D^*	D^*/σ_D
II ...	21.07*	21.22	_19.66_*	_21.44_	19.89	20.55	20.55	1.78	2.07	–2.41	3.60
III ...	14.73*	_13.33_*	14.66	13.44	14.22	_14.99_	14.13	1.66	1.36	–1.40	1.51
V ...	11.73*	11.44	12.44	_12.55_	11.00	_10.77_*	11.64	–1.78	1.41	–0.96	1.17
VI ...	14.40*	_13.11_*	14.66	13.66	14.44	_15.66_	14.31	2.55	2.42	–1.29	1.59
VIII ...	15.16*	_15.22_	15.00	13.89	_13.67_*	14.11	14.38	–1.55	2.72	–1.49	2.48
IX ...	12.57*	12.77	12.55	_13.33_	13.11	_10.66_*	12.48	–2.67	2.38	–1.91	2.34
X ...	13.97*	13.78	_13.11_*	_14.44_	14.22	14.33	13.89	1.33	2.21	–0.86	3.30
XV ...	7.20*	7.66	_7.66_	7.11	_5.85_*	6.63	6.99	–1.81	2.58	–1.35	2.30
Mean ...	13.69*	13.57	13.72	_13.73_	_13.30_*	13.46	13.54	–0.43	0.23	–0.39	0.20

D—differences between italicized means is compared.
D*—differences between starred means is compared.

pressure for a long period of time, was chosen for this section of the experiment. Five degrees of exertion were used, viz.—E1—8 lbs.; E2—15 lbs.; E3—22 lbs.; E4—48 lbs.; E5—56 lbs., each hand.

Table VIII shows the results for 8 subjects in speed of continuous addition (30 sec. trials). A glance at the column headed D/σ_D will show that none of the inter-exertion differences are reliable. More important, still, however, is the lack of consistent trend in the direction of the results for the 8 subjects. Subject II shows an 'optimum' at E3; but the difference here is undoubtedly not reliable since the larger difference between E2 and C is just above conventional requirements—$D/\sigma_D = 3.60$. Subject III shows an 'optimum' at E5, subject V at E3, subject VI at E5, subject VIII at E1, subject IX at E3 and subject X at E2 or E1. The means for all 8 subjects show an 'optimum' at E3, but the difference between E3 and C is only $+0.04$ and undoubtedly not reliable.

Table IX makes more vivid the trend of these results. Each degree of exertion is ranked for each of the 8 subjects. The mean

TABLE IX

OPTIMA

Ranks for degrees of exertion

Subject	E_1	E_2	E_3	E_4	E_5
II	2	5	1	4	3
III	5	2	4	3	1
V	3	2	1	4	5
VI	5	2	4	3	1
VIII	1	2	4	5	3
IX	3	4	1	2	5
X	4	5	1	3	2
XV	1.5	1.5	3	5	4
Mean	3.06	2.94	2.34	3.63	3.00

rank for each degree of exertion approximates 3, which is exactly what would be expected by chance. Table X shows more clearly the

TABLE X

OPTIMA

Distribution of ranks

Rank	E_1	E_2	E_3	E_4	E_5
1	1.5	0.5	4	0	2
2	1.5	4.5	0	1	1
3	2	0	1	3	2
4	1	1	3	2	1
5	2	2	0	2	2

TABLE XI

OPTIMA

Average number errors per 30 sec. trial in continuous addition

		8 lb.	*15 lb.*	*22 lb.*	*48 lb.*	*56 lb.*					
	C	E_1	E_2	E_3	E_4	E_5	E_{all}	*D*	D/σ_D	D^*	D^*/σ_D
II ...	0.73*	*1.55*	1.77	1.66	*2.33**	1.77	1.82	–0.78	1.25	–0.60	1.09
III ...	0.73*	*0.89*	0.78	0.66	0.77	*0.55**	0.73	0.34	1.36	0.18	3.00
V ...	0.27*	0.66	*0.89**	0.22	0.44	*0.11*	0.77	0.78	2.88	–0.62	2.38
VI ...	0.90*	1.89	*2.11**	0.89	1.22	*0.88*	1.38	1.23	1.83	–1.21	3.18
VIII ...	0.70*	0.89	0.33	*1.22**	*0.33*	1.11	0.78	0.89	1.81	–0.52	2.00
IX ...	0.97*	1.55	*1.00*	1.11	1.44	*2.33**	1.49	–1.33	3.00	–1.36	3.88
X ...	0.43*	0.66	*0.55*	0.55	0.55	*0.89**	1.07	–0.34	0.94	–0.46	1.70
XV ...	0.66*	*0.44*	0.66	0.44	*1.22**	0.78	0.71	–0.78	2.88	–0.56	1.80
Mean ...	0.80*	*1.07**	1.01	*0.84*	1.04	1.05	0.996	0.23	1.00	–0.27	1.17

D—difference between italicized means is compared.
D*—difference between starred means is compared.

distribution of optima for individuals. E3 and E2 show a slight tendency to be ranked first and second, *i.e.*, they rank first and second, respectively, for half of the 8 subjects. The other degrees of exertion show no distinguishable tendencies.

Table XI shows results of 8 subjects in accuracy of continuous addition. Here, but one of the inter-exertion differences is reliable —that between E2 and E5 for subject IX—showing an increased number of errors as the amount of exertion increases. For the rest, the inter-exertion differences exhibit no consistent trends. Table XII shows this lack of consistent tendency more clearly. The

TABLE XII

OPTIMA

Ranks for degrees of exertion

Subject	E_1	E_2	E_3	E_4	E_5
II	1	3.5	2	5	3.5
III	5	4	2	3	1
V	4	5	2	3	1
VI	4	5	2	3	1
VIII	3	1.5	5	1.5	4
IX	4	1	2	3	5
X	4	2	2	2	5
XV	1.5	3	1.5	5	4
Mean	3.31	3.12	2.31	3.19	3.06

average rank for all degrees of exertion again approximates 3, except possibly the third degree of exertion (22 lbs.) which is slightly more favored than the others. This slight difference perhaps

assumes a bit more significance when it is remembered that E3 was also somewhat favored for speed of continuous addition. Nor can this difference be attributed to the temporal position of E3 in the series of pressures, since this was varied in the three sessions (see

TABLE XIII
OPTIMA
Distribution of ranks

Rank	E_1	E_2	E_3	E_4	E_5
1	1.5	1.5	1.5	1.5	3
2	0.5	1.5	6.5	1.5	0
3	1	1.5	0	4	0.5
4	4	1.5	0	0	2.5
5	1	2	1	2	2

above, p. 17). Table XIII shows the distribution of ranks for the 8 subjects. The advantage of E3 is most clearly demonstrated in this Table, since more than ¾ of the subjects show it ranking second in the series.

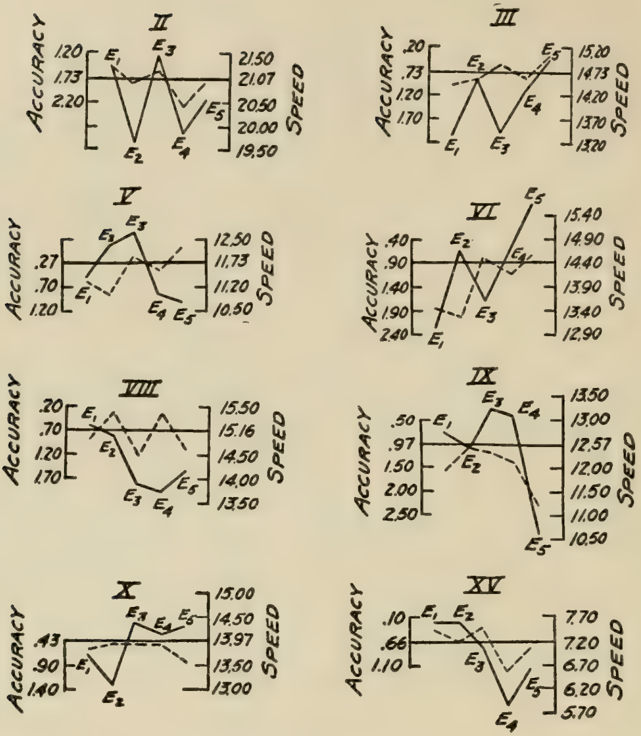
Figure 6 graphically represents the results in speed and accuracy for the 8 subjects. The base line for each graph is the control performance in both speed and accuracy. The unbroken line represents speed; the dotted line, errors. It is clear from inspection of these curves that there is no reliable 'optimal' degree of exertion either for individual subjects or for the group. E3 has, it is true, a tendency, noted above, to be the best of the series, but it is not, in any real sense an 'optimum,' since, on the whole, it is but very slightly better than the control condition, and for some subjects slightly worse. A tendency is also apparent for the curves of speed and accuracy to run parallel with each other, except in the case of subject X.

Figure 7 shows the curves of speed and accuracy for all 8 subjects combined. No optimum degree of exertion is revealed. Again the curves for accuracy and speed parallel each other.

Introspective Reports

Introspective reports are of as little value in this section of the experiment as before. None of the subjects offered a report when questioned. Additional questions revealed that of all the degrees of exertion, E5 was occasionally felt to be annoying; each trial was so short, however, that even E5 was never really 'disagreeable'.

FIGURE 6


II
III
V
VI
VIII
IX
X
XV
ACCURACY
SPEED

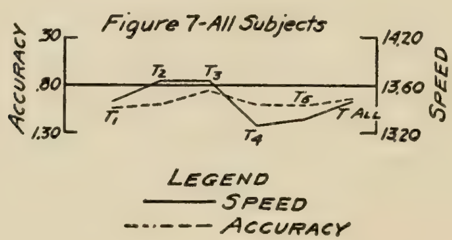


Figure 7-All Subjects
ACCURACY
SPEED
.30
.80
1.30
14.20
13.60
13.20
LEGEND
SPEED
ACCURACY

Summary

(1) No optimum degree of exertion appears for a group of 8 subjects, with either speed or accuracy of continuous addition as criterion.

(2) Half of the subjects slightly favor 22 lbs. of hand pressure

TABLE XIV

Summary

(All subjects; N = 15)

Task		*D*	*D*/σ_D
Addition	*Speed*	–0.93	0.16
N = 14	*Errors*	–0.36	0.31
Syllogisms	*Speed*		
N = 9	Hands	+0.67	0.33
	Foot	+0.63	0.21
	H–F	–0.58	0.23
	All	+0.45	0.27
	Errors		
	Hands	–0.002	
	All	–0.210	
Analogies	*Speed*		
N = 10	Hands	+0.03	0.03
	Foot	–0.04	0.08
	H–F	+0.88	0.50
	All	+0.29	0.36
	Errors		
	Hands	–0.14	
	Foot	–0.13	
	H–F	+0.43	
	All	–0.02	
Optima (Cont. Addition)	*Speed*		
	E1	–0.12	
N = 8	E2	+0.03	
	E3	+0.04	0.02
	E4	–0.39	0.20
	E5	–0.23	
	E all	–0.15	0.076
	Errors		
	E1	–0.27	1.17
	E2	–0.21	
	E3	–0.04	
	E4	–0.24	
	E5	–0.25	
	E all	–0.196	0.81

+ = exertion advantage.
– = control advantage.

TABLE XV
Individual Consistency

	A		B								C								D											
	Cont. Add.		Syllogisms								Analogies								Optima (Continuous Addition)											
	Speed	Errors	Speed				Errors				Speed				Errors				Speed						Errors					
			H	*F*	*H & F*	*All*	*H*	*F*	*H & F*	*All*	*H*	*F*	*H & F*	*All*	*H*	*F*	*H & F*	*All*	E_1	E_2	E_3	E_4	E_5	E_{all}	E_1	E_2	E_3	E_4	E_5	E_{all}
I	=	+	+	−	−	+	+	+	−	=	+	−	+	+	−	−	−	−												
II	−	−	+	+	+	+	=	−	−	−	+	−	−	−	=	−	−	−	+	−	+	−	−	−	+	−	+	−	−	−
III	−	+	+	+	+	+	−	+	−	−	+	+	−	+	+	=	+	+	−	−	−	−	+	−	−	−	+	+	−	=
IV	−	−	+	−	−	−	+	+	−	=	+	−	+	+	−	−	+	+												
V	+	−	−	−	−	−	−	−	−	−	−	−	+	+	−	−	+	−	−	+	+	−	−	−	−	−	+	−	+	−
VI	+	−									−	−	−	−	−	+	+	+	−	+	−	+	+	−	−	−	+	−	+	−
VII	−	−	+	−	−	+	−	−	−	−	−	+	+	+	+	+	+	+												
VIII	−	−	=	+	−	+	+	=	−	+	−	+	+	+	=	−	+	+	+	−	−	−	−	−	−	+	−	+	−	−
IX	+	−	−	+	−	−	+	=	−	+	+	=	−	−	−	=	+	−	+	−	−	−	−	−	−	−	−	−	−	−
X	+	−	+	+	−	+	+	−	−	−	−	+	+	+	−	=	−	−	−	−	+	+	+	=	−	−	−	−	−	−
XI	−	−																												
XII	+	+																												
XIII	−	−																												
XIV	−	−																												
XV																			+	+	−	−	−	−	+	=	+	−	−	−

where speed is the criterion; $\frac{3}{4}$ of them favor 22 lbs. (rank 2) where accuracy is criterion.

(3) None of these scores, however, is significantly greater than control performance.

(E) Summary of Results

(1) *Group Differences*

Table XIV summarizes the group differences for all four parts of the experiment. A glance at the Table shows that all differences are small, unreliable and inconsistent in trend.

(2) *Individual Differences*

Table XV was prepared with the purpose of showing possibly consistent trends for individual subjects. No such consistency is apparent for any one subject.

CHAPTER IV

DISCUSSION OF RESULTS

Our results, then, are clearly negative for the hypothesis that increased physical exertion will facilitate mental performance. In this respect, they are in agreement with Zartman and Cason's results and apparently contradictory to Bills'. It is interesting to speculate on the reasons for this apparent contradiction. To begin with, it should be remembered that there were wide individual differences in the extent to which Bills' subjects exhibited the facilitative effects of exertion. All Bills' subjects, it is true, showed positive tendencies in the ''paired associates'' test; we have, however, already raised a theoretical objection (see above, p. 7) to the significance of Bills' results in this ''paired associates'' section. Where the task was simple addition, all of Bills' subjects again showed a positive tendency, but in 5 of the 11 cases the differences were quite unreliably greater than zero. In the two remaining sections of his experiment, on the other hand, there were at least 3 and sometimes as many as 5 subjects (half the total number) who did not show exertion advantage. In all sections of our experiment, similarly, there were at least 3 subjects and sometimes over half the total number who *did* show exertion advantage. Table XVI tabulates the number of subjects showing exertion advantage and the number showing control advantage in each section of Bills' experiment and ours. When this Table is carefully examined, it is apparent that the discrepancy between the two sets of results is not so large as a more superficial analysis might indicate. With samples of population as small as those in Bills' experiment and in our own, it is to be expected that differences small to begin with will occur sporadically, sometimes in a few individuals, again not in others, sometimes in one direction, sometimes contrariwise.

It is somewhat more difficult to explain the discrepancy between the reliability of Bills' group-average differences and the unreliability of our own. Obviously, of course, those of Bills' subjects who did show exertion advantage must have shown relatively large differences, which, overbalancing negative instances, contributed to a significant difference between means. Why Bills' subjects should have shown larger positive differences than our subjects becomes the problem. It is, in the first place, always possible to point once more to individual differences and the small samples of the popula-

TABLE XVI

COMPARISON OF PRESENT RESULTS WITH BILLS'

Number subjects exhibiting exertion or control advantage in all sections of both experiments

	N=14	*N=9*				*N=10*				*N=8*						
	Cont. Add.	*Syllogisms*				*Analogies*				*Optima (Cont. Add.)*						
		H	*F*	*H–F*	*All*	*H*	*F*	*H–F*	*All*	*E1*	*E2*	*E3*	*E4*	*E5*	*Eall*	
No. S.'s +	5	6	5	2	6	5	4	6	7	4	3	3	2	3	0	
No. S.'s –	8	2	4	7	3	5	5	4	3	4	5	5	6	5	7	Speed
No. S.'s =	1	1	0	0	0	0	1	0	0	0	0	0	0	0	1	
No. S.'s +	3	5	4	0	2	2	2	6	7	2	1	5	2	2	0	
No. S.'s –	11	3	3	9	5	6	5	4	3	6	6	3	6	6	7	Errors
No. S.'s =	0	1	2	0	2	2	3	0	0	0	1	0	0	0	1	

	N=9 *Nonsense Syllables*				*N=11*	*N=11*	*N=10*
	Time	*Syll.*	*Re-learn. Time*	*% Saved*	*Pair. Assoc.*	*Addition*	*Reading*
No. S.'s +	6	5	7	7	11	11	6
No. S.'s –	3	2	2	2	0	0	2
No. S.'s =	0	2	0	0	0	0	2
			(3 cases unreliab. diff.)	(4 cases unreliab. diff.)		(5 cases unreliab. diff.)	

tions in both studies, implying, thus, that the differences in the results were differences inherent in the two sets of subjects.

Or it may be that the differences in results were a function of a difference in experimental conditions in both studies. Most important of these possible differences seems to us to be the amounts of 'double-task' (exertion—mental work) practice which the subjects were permitted. Bills changed his subjects in each part of the experiment; the majority of subjects in our experiment stayed through all four parts. It may safely be supposed, therefore, that, in the last three sections of our experiment—syllogisms, analogies and continuous addition (short periods), our subjects were considerably better habituated than the subjects in the last three sections of Bills' experiment—paired associates, continuous addition and letter naming. Two possible effects of this increased habituation may theoretically be supposed to occur: 1) Habituation, acting to decrease the influence of distraction, might allow the 'pure' physiological effect of proprioceptive impulses to become progressively more apparent. Some sections of Bills' study might be cited as evidence for this first hypothesis. In speed of simple addition, the initial differences in favor of the exertion series are, Bills re-

ports, somewhat enhanced by practice. The accuracy ratio, however, remains the same. Curves for individual subjects, further, are not presented so that it is impossible to know how general these effects are. The practice curves for the results of the paired associates test show exertion consistently maintaining its advantage over control. The advantage, however, does not *increase* with practice, which a strict interpretation of the first hypothesis would demand. Further, the technique of the paired associates experiment, as pointed out above (see p. 7) makes conclusions from it regarding the effects of proprioceptive impulses impossible. 2) Habituation, acting to decrease the influence of distraction, might thereby decrease initial differences between control and exertion responses. This second hypothesis is based on either of two assumptions, viz.: a) that there is no facilitative effect of additional proprioceptive stimulation, so that exertion simply behaves as a distraction, or as an impetus to increased motivation; or, b) a true physiological facilitation effect exists, but is confined to the early stages of practice. According to the second of these assumptions, the initially facilitative effects of proprioceptive impulses would be functionally indistinguishable from the effects of distraction, or of a double-task situation, although a theoretical distinction between the two influences might be drawn.

Somewhat stronger evidence may be found for our second hypothesis than for our first. There is considerable evidence in the psychological literature (Jersild (13)) that the initially detrimental effects of a double-task situation decrease or disappear with practice, *i.e.,* as the second task becomes 'integrated' with the first. Bills' practice curves for learning nonsense syllables show that where number of syllables recalled and percent time saved are criteria, a marked convergence of the two curves occurs. In our own results, the effects of exertion tend to decrease with practice in continuous addition (see above, p. 20). This second hypothesis also checks with

TABLE XVII

SIZE OF POSITIVE DIFFERENCES FOR ALL SUBJECTS

	Additions (N = 9)	*Syllogisms (N = 9)*				*Analogies (N = 9)*			
	Continuous	*Hands*	*Foot*	*Hands-Foot*	*All*	*Hands*	*Foot*	*Hands-Foot*	*All*
Speed	....	6%	4%	.....	3%	4%	.....	9%	9%
Errors	....	....			....	....	.....	14%	....

the suggestion in our own results that the largest differences for individual subjects occurred in the first and second sections of our experiment—continuous addition and syllogisms. Tables XVII, XVIII, XIX and XX reveal the extent of this tendency. When all

TABLE XVIII

SIZE OF POSITIVE DIFFERENCES FOR EACH SUBJECT (HAND EXERTION)

	Continuous Addition	*Syllogisms*	*Analogies*
I	=	4%	10%
II	......	28%	5%
III	......	9%	15%
IV	......	3%	4%
V	6%	......	......
VI	0.5%	absent	......
VII	......	18%	......
VIII	......	=	......
IX	8%	......	0.9%
X	7%	5%	......

TABLE XIX

SIZE OF POSITIVE DIFFERENCES FOR EACH SUBJECT IN 3 TESTS

	Continuous Addition	*Syllogisms*				*Analogies*			
		H	*F*	*H & F*	*All*	*H*	*F*	*H & F*	*All*
I	=	4%	......	......	0.3%	10%	......	18%	10%
II	......	28	2.5	0.3	20	5	......	......	......
III	......	9	4	13	15	15	18	......	6
IV	......	3	......	......	......	4	......	14	3
V	6%	......	......	......	......	......	......	34	11
VI	0.5	absent			......	......	......	......	......
VII	......	18	......	......	6	......	3	20	8
VIII	......	=	12	......	0.6	......	9	24	11
IX	8	......	2	......	......	0.9	......	......	......
X	7	5	10	......	0.4	......	0.6	0.6	0.3

TABLE XX

SIZE OF POSITIVE DIFFERENCE FOR INDIVIDUAL SUBJECTS IN 3 TESTS

	Cont. Add.	*Syllogisms*				*Analogies*			
		H	*F*	*H & F*	*All*	*H*	*F*	*H & F*	*All*
V	6%	......	......	......	......	......	......	34%	11%
VI	0.5	absent				......	......	......	......
IX	8%	......	2	......	......	0.9	......	......	......
X	7%	5%	10%	......	0.4	......	0.6	0.6	0.3

subjects are considered together (Table XVII), positive differences in speed and accuracy decrease slightly or are reversed during the syllogisms test. A recurrence of positive difference may be noted in the analogies test under hand-foot exertion. Accuracy differences are all negative, except, again, under hand-foot exertion in the analogies test. Table XVIII indicates the progressive changes in relative amounts of difference as the experiment proceeds, with speed of response as criterion. Reading horizontally, we see that, with the exception of subjects I and III, the differences (in percentage terms) are smaller in the analogies series than in the syllogisms test, when just hand exertion results are considered.[1, 2] When all exertion conditions are included in the analysis, as in Table XIX, the same tendency is apparent, with subjects I and III again excluded, and with a reversal of the trend in the hand-foot part of the analogies experiment. (Here, 5 of the 10 subjects show large increases in the positive direction.) When only those subjects who showed positive differences in the very first section of the experiment (continuous addition) are studied (Table XX), the same tendency for these differences to decrease, disappear, or be reversed as the experiment proceeds, may be noted. Definite conclusions for either of our two hypotheses cannot, of course, be drawn, since the evidence from our own results is masked by differences in the type of material used in the several sections of the experiment. But the weight of evidence seems inclined toward a theory which confines the effects of exertion to early work stages. Since, further, there can be no doubt that our subjects were very much more habituated to exertion conditions than Bills', a possible explanation for the discrepancy between his results and ours is apparent.

Lastly, it is possible that the difference between Bills' and our results was a function of the degree of exertion involved in both experiments. Bills nowhere states the exact amount of pressure required from his subjects. The negative results from the optima section of this experiment would tend, however, to discount this possibility.

The implications of our results for Freeman's theory of cortical facilitation and for other theories of consciousness (*e.g.*, Guthrie's (11)) which lay stress on the importance of proprioceptive impulses in general mental activity, must concern us next. Insofar as these

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[1] Results from the last part of the experiment are excluded from consideration here, since non-comparable exertion conditions were used.

[2] Minor differences in the case of subjects IV and IX are disregarded.

theories demand that complex 'mental' responses shall be facilitated by generalized increases in the activity of the peripheral musculature, our results offer no confirmation. The trend of previous work, too, as was pointed out above, seems to indicate, rather, merely the facilitation of simple, specific motor acts by the contraction of near-by muscle groups. For the somewhat broader question whether cortical processes are facilitated by increases in proprioceptive tonus, our results do not present conclusive evidence. It is doubtful whether any study such as this, which allows volitional and motivational factors to enter so markedly into the experimental set-up can offer crucial evidence for this problem. Such volitional and motivational factors can act only to mask whatever physiological effects of proprioceptive impulses do exist. The negative results of Zartman and Cason's study and of this one, and the somewhat confused results of Bills' work ought, perhaps, to serve as an indication that this kind of approach to the field of motor activities and consciousness deceptively simplifies the problem.

CHAPTER V

SUMMARY AND CONCLUSIONS

1) The effect of voluntarily induced muscular contraction on speed and accuracy of human performance at tasks of varying difficulty was studied in 15 male subjects.

2) An apparatus was constructed which allowed the subject to exert a stated amount of hand or foot pressure at the same time that he did mental work. Record in pounds was kept of the degree of pressure exerted. The apparatus was so constructed that it was impossible in the experimental series for the subject to do the mental task unless he was maintaining a steady degree of pressure. In the control series, no appreciable pressure was exerted.

3) Differences between group-averages for the two series in speed and accuracy of continuous addition (3 minute periods), syllogistic reasoning and selection of analogies were small, variable in direction and statistically insignificant. This result held for hand pressure, foot pressure and both combined.

4) Individual differences were widespread and inconsistent in all tests, under all exertion conditions.

5) No optimum degree of exertion was found in a test using five ascending degrees of hand pressure accompanying 30 second periods of continuous addition. Individual differences were again large.

6) Our results are thus in agreement with Zartman and Cason's and apparently contradictory to those of Bills. An attempt is made to explain this discrepancy on several grounds: a) Differences in the samples of the population tested. Bills' subjects, it should be noted, showed wide individual differences similar to ours. b) Differences in the exertion conditions, although the negative results on optima throw doubt on this possibility. c) Differences in the degree of practice in the 'exertion situation' between Bills' subjects and ours.

7) Our results, since they are undoubtedly overlaid by volitional and motivational factors, are considered to be inconclusive for any motor theory of consciousness.

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APPENDIX

Tables Showing Raw Data in Speed and Accuracy of Continuous Addition[1]

A. Speed

	Trials	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
SI	C	38	41	38	43	39	37	36	40	40	32	37	46	38	40	51
	E	31	34	54	33	36	39	36	34	27	37	41	38	44	49	44
SII	C	59	86	80	75	86	82	88	85	85						
	E	57	75	66	63	75	80	80	77	83						
SIII	C	31	42	42	50	40	45	44	38	35	47	37	44	53	45	
	E	19	30	43	37	42	51	40	35	38	42	51	38	57	35	
SIV	C	50	59	60	58	61										
	E	38	57	50	52	61										
SV	C	33	36	41	45	44	49	48	47	49						
	E	40	40	49	42	43	45	49	51	56						
SVI	C	31	44	50	46	58	53	52	57	54	65	58	60	50		
	E	35	46	52	46	52	46	54	55	50	60	61	63	62		
SVII	C	54	60	51	69	70	68	73	74							
	E	66	62	59	58	64	59	71	74							
SVIII	C	50	53	50	48	57	51	56	49							
	E	55	52	42	44	55	51	52	51							
SIX	C	27	34	37	43	37	45	42								
	E	28	33	36	35	47	50	49								
SX	C	31	43	65	54	60										
	E	49	60	65	45	60										
SXI	C	19	21	25	24	23	26	27	23							
	E	20	18	26	23	22	25	25	23							
SXII	C	40	41	43	40	41	42	43	40	41	41					
	E	50	44	43	42	42	43	44	42	41	41					
SXIII	C	51	60	59	62	63	60	59	57	58	59	60	57	58	58	58
	E	47	57	54	60	57	58	57	56	57	58	58	56	58	58	58
SXIV	C	44	42	43	42	40	39	40	40	36						
	E	38	40	39	40	38	39	38	38	35						

[1] The averages of each session's performance (3 or 4 trials) have in turn been averaged to get the final average reported in Tables I and II. Hence there may, in some cases, be a slight discrepancy between the averages in Tables I and II and the average obtained by adding each score as a unit.

B. Errors

	Trials	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
SI	C	6	5	5	6	5	0	4	1	5	4	0	0	0	1	0
	E	6	7	4	3	0	0	1	1	0	0	3	0	0	1	0
SII	C	4	8	5	8	3	4	7	7	8						
	E	7	2	8	7	6	3	10	9	9						
SIII	C	5	4	1	6	4	2	0	4	3	3	1	2	2	2	
	E	2	3	2	1	1	1	1	2	2	4	1	3	4	1	
SIV	C	5	8	9	8	8										
	E	11	11	5	11	10										
SV	C	3	5	5	4	7	1	4	5	3						
	E	6	3	7	5	1	7	3	5	6						
SVI	C	3	2	4	0	0	9	4	5	6	1	3	4	4		
	E	6	8	8	5	0	3	1	6	4	3	3	1	3		
SVII	C	9	5	4	4	2	1	3	4							
	E	2	8	6	3	5	7	2	3							
SVIII	C	3	1	5	4	6	6	2	3							
	E	4	4	3	4	6	7	5	3							
SIX	C	4	4	1	3	3	4	2								
	E	6	3	7	3	3	2	2								
SX	C	4	2	5	6	1										
	E	6	5	4	7	1										
SXI	C	3	2	4	3	3	2	5	3							
	E	5	4	3	4	3	3	3	3							
SXII	C	15	16	13	12	10	12	12	13	14	13					
	E	11	9	6	5	8	8	6	8	7	7					
SXIII	C	10	8	5	7	4	3	4	2	3	2	3	2	3	1	
	E	11	10	10	7	5	4	5	3	2	3	4	1	1	0	
SXIV	C	3	6	4	5	3	4	2	2	1						
	E	10	11	5	6	4	5	5	4	1						

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